# Multi-stage arc magma evolution recorded by apatite in volcanic rocks

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**D1606 | EGU2020-1405**

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# Presentation outline

**Full paper available at:** Chetan L. Nathwani, Matthew A. Loader, Jamie J. Wilkinson, Yannick Buret, Robert H. Sievwright, Pete Hollings; Multi-stage arc magma evolution recorded by apatite in volcanic rocks. *Geology* ; 48 (4): 323–327. doi: https://doi.org/10.1130/G46998.1

**Outline:**

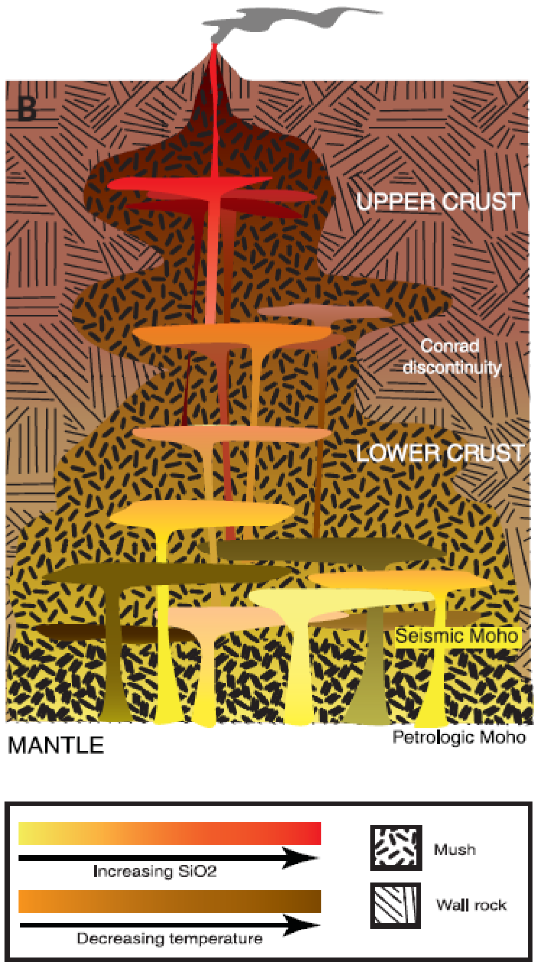
1. Introduction – why study apatite chemistry in volcanic rocks?
2. Petrography – apatite textures
3. Data from apatites from Central Chilean volcanics
4. Trace element fractional crystallization modelling of apatite chemistry
5. Implications and conclusions

# Research motivations

1. Can apatite archive the evolution of melts in magmatic arcs (with a focus on Sr/Y and Eu/Eu*)? To what extent does it record deeper vs shallower magma evolution?

2. Can apatite fingerprint magmas that have undergone a deep, water-rich magma evolution history (in a thick, metallogenically fertile arc)?

3. To what extent is apatite chemistry coupled to the bulk magma/whole-rock chemistry?




Cashman et al. (2017)

# Apatite: an archive of magmatic evolution?

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**Why use apatite to indicate petrogenetic processes?**

**(1) Chemically versatile**

- Partitions Sr, Y and the REEs
- Also partitions halogens and sulphur

**(2) Track melt evolution**

- Whole-rock records single, late state of magmatic history
- Apatite records protracted and earlier magmatic history

**(3) Not sensitive to crystal accumulation**

- Whole-rock Sr/Y very sensitive to plagioclase accumulation

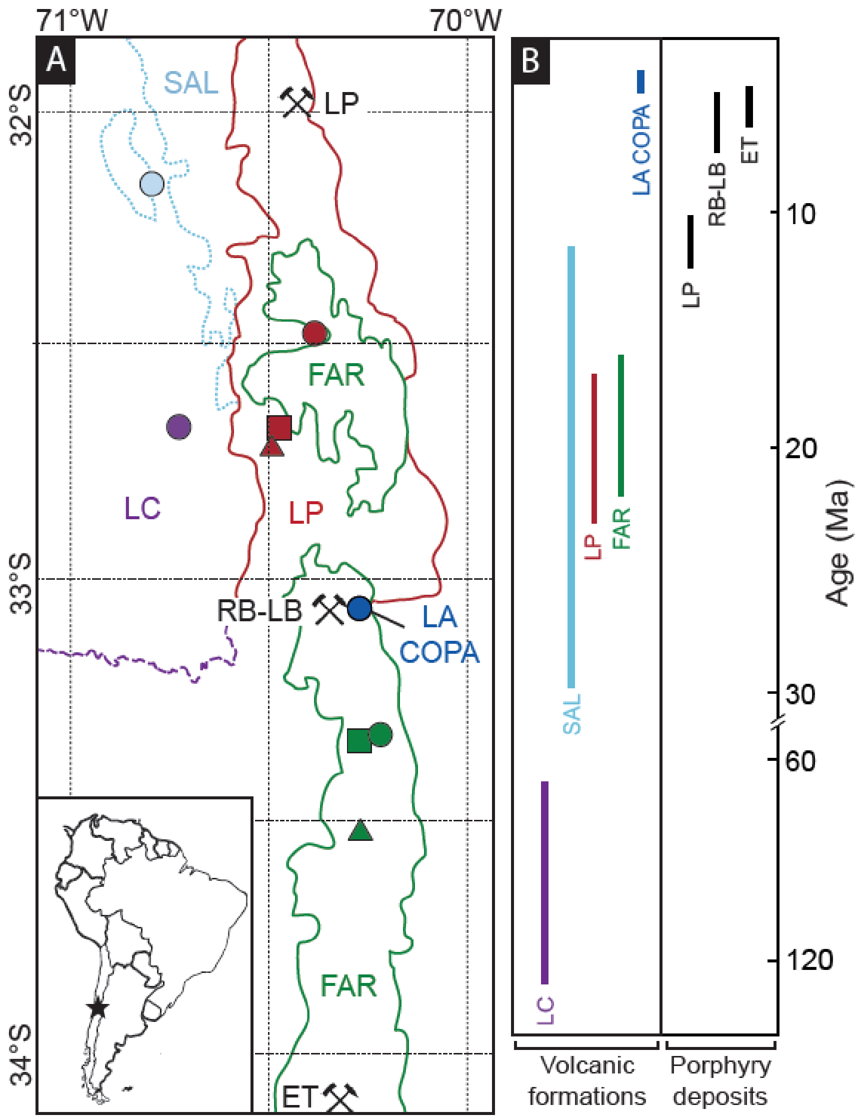
**(4) More robust to alteration**

- Feldspars easily altered and Sr highly mobile in whole-rock

# Study area and sampled units

**Cenozoic Central Chilean volcanic stratigraphy:**

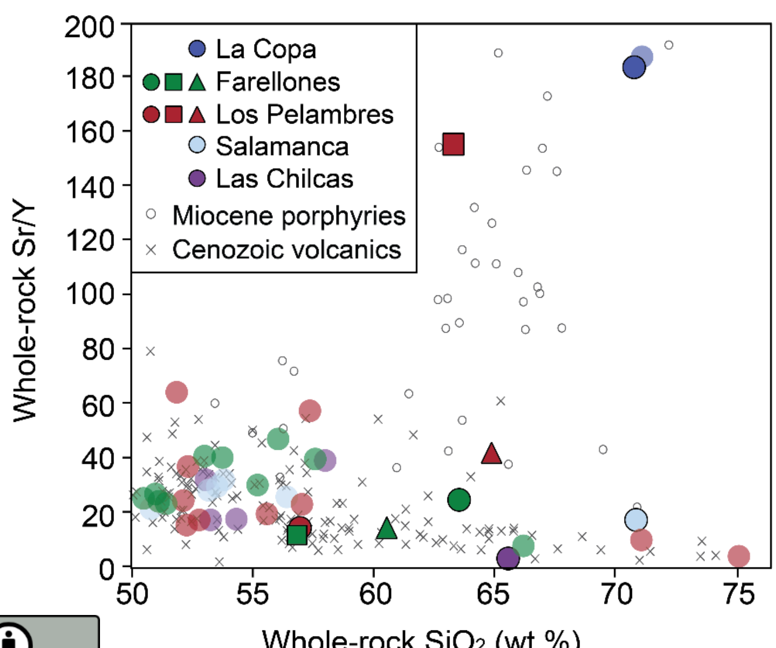
- Las Chilcas Formation (Cretaceous)
- Salamanca Formation (30.1-11.4 Ma)
- Los Pelambres Formation (23.1-16.8 Ma)
- Farellones Formation (22-16 Ma)
- La Copa Rhyolite (4.9-3.9 Ma)

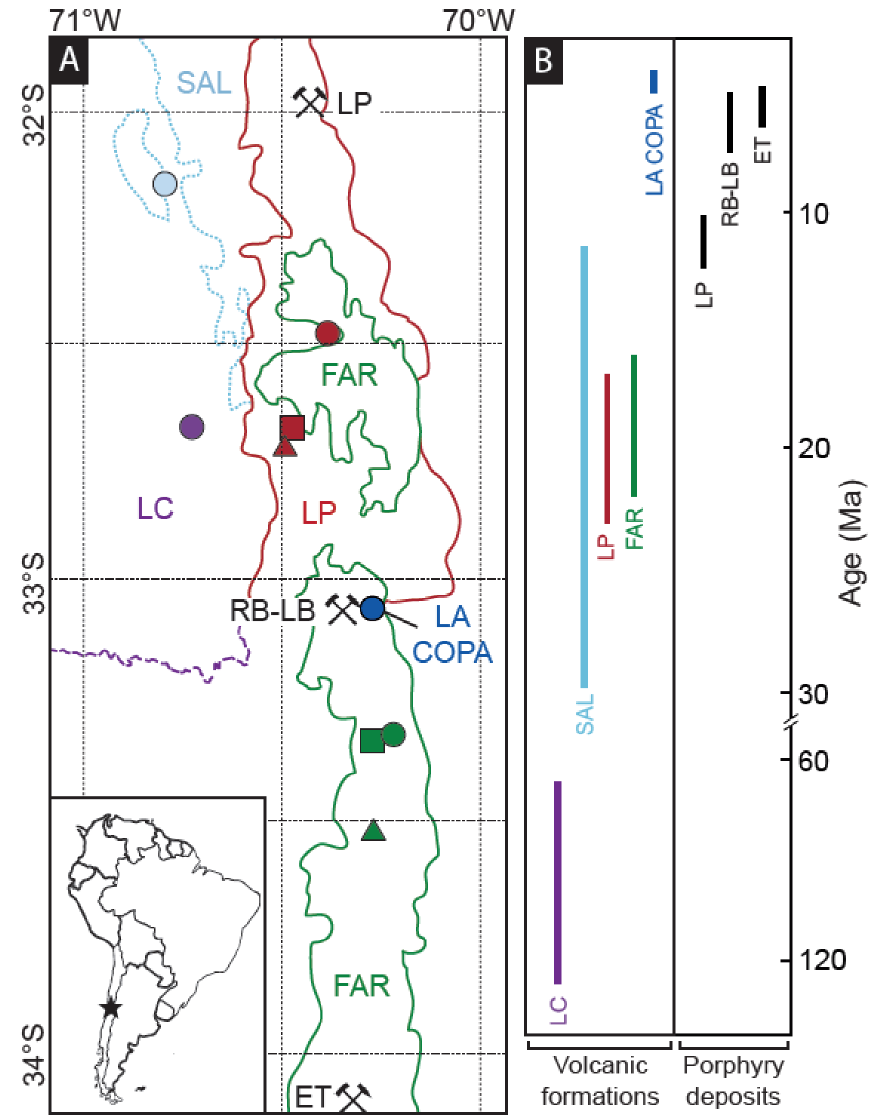


# Study area and sampled units

**This magmatic epoch culminated in arc thickening, hydrous, high Sr/Y magmas that formed three giant porphyry Cu deposits:**

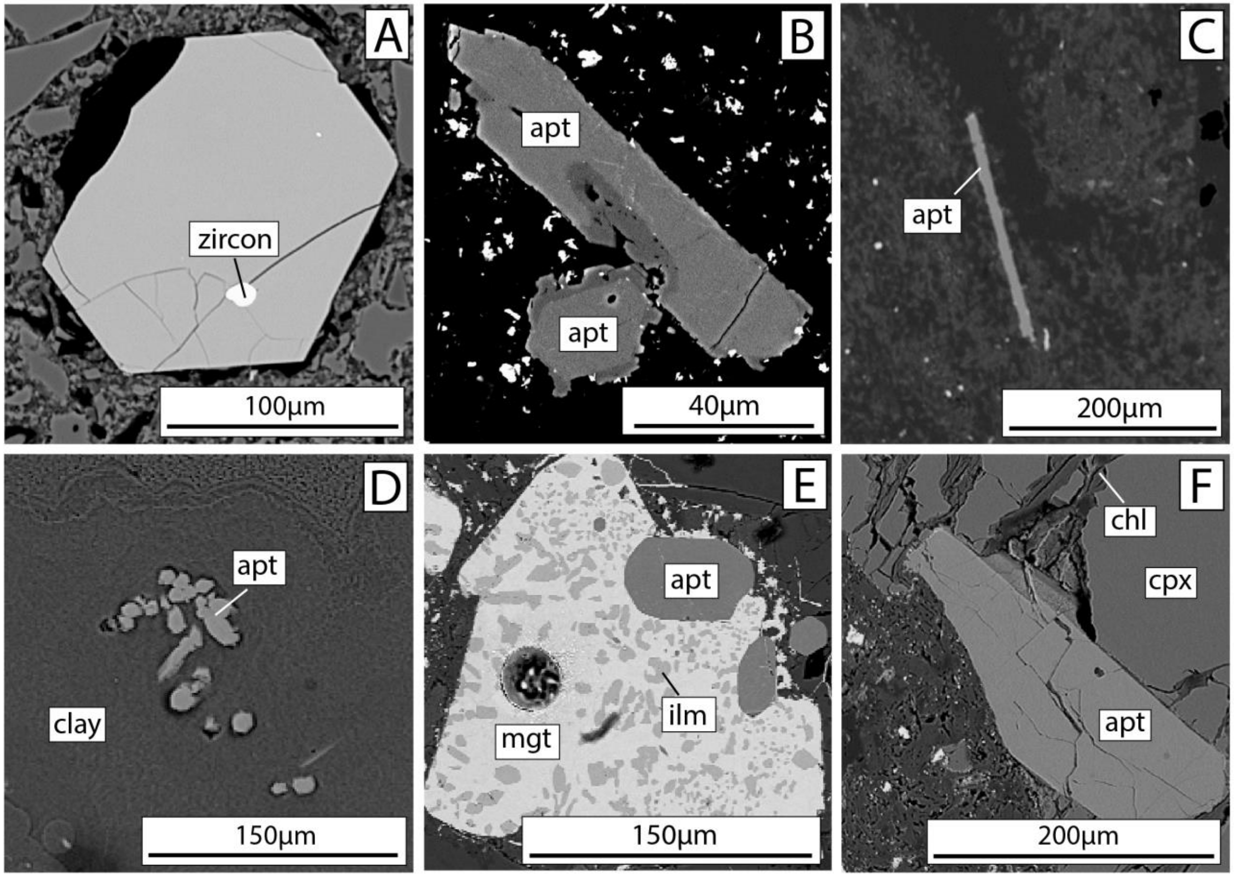
1) Los Pelambres (9.5-10.5 Ma)
2) Rio Blano-Los Bronces (7.4-4.9 Ma)
3) El Teniente (6.3-4.6 Ma)



# Apatite habits and textures

**Apatite crystals generally found as microphenocrysts in groundmass or associated with magnetite. Some as inclusions in other minerals. Minor secondary apatite present.**



# Apatite habits and textures

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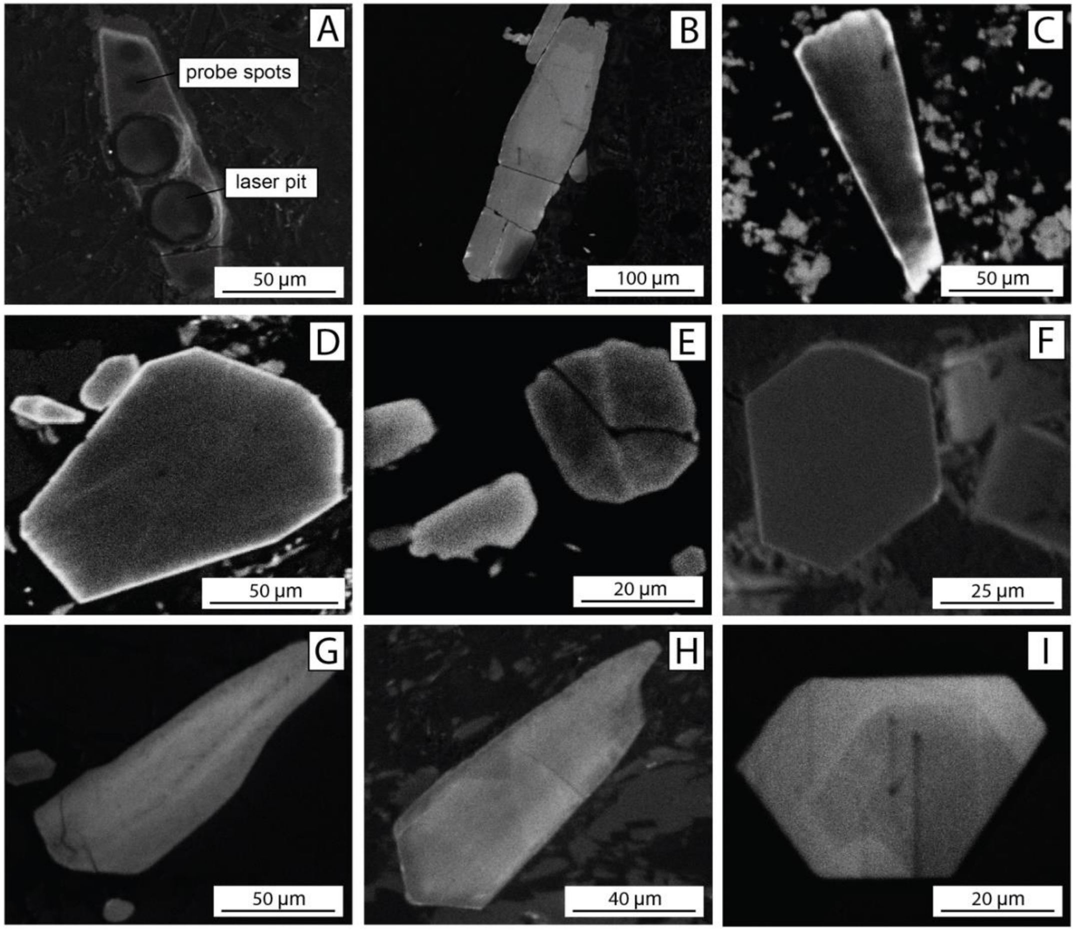
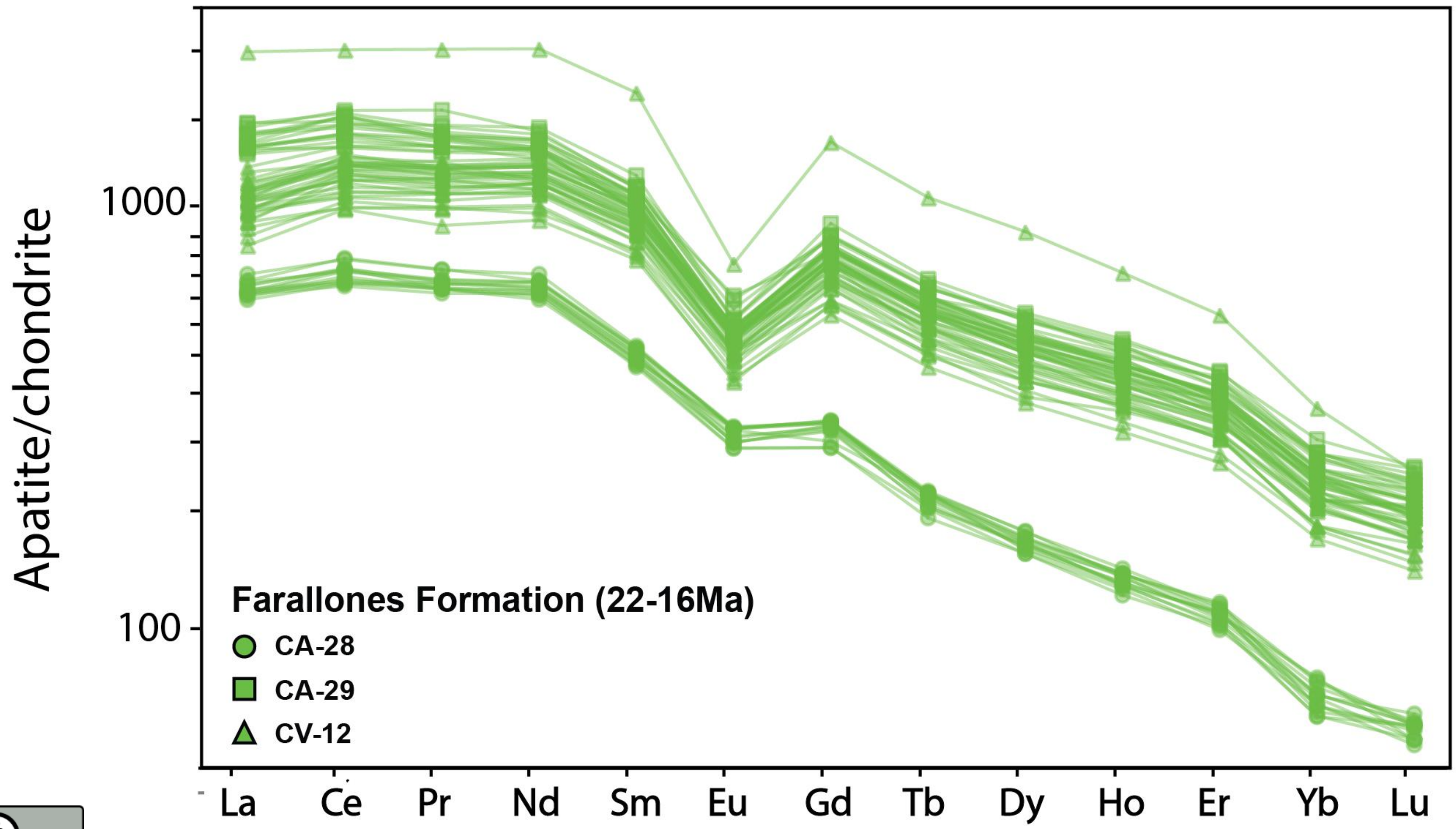
**SEM cathodoluminescence imaging of apatite generally showed preservation of magmatic zoning, and therefore suggesting minimal secondary hydrothermal overprint**



# Apatite REE chemistry

**Apatite REE patterns demonstrate high LREE relative to HREE concentrations, and variably negative Eu anomalies – all typical of igneous apatite**



# Apatite trace element chemistry

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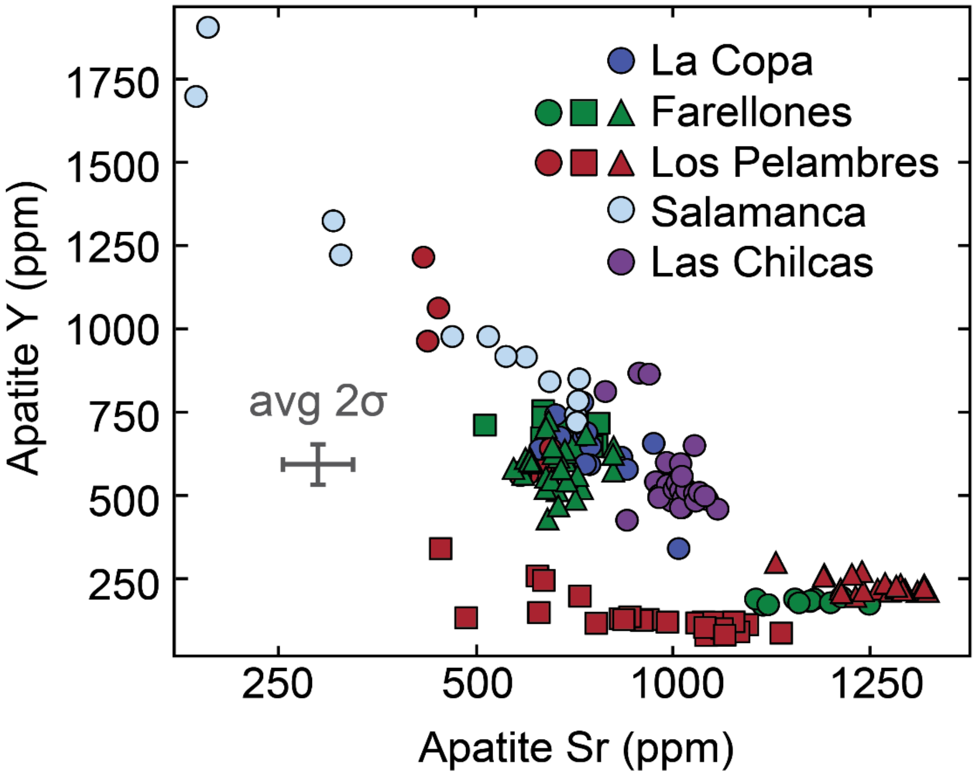
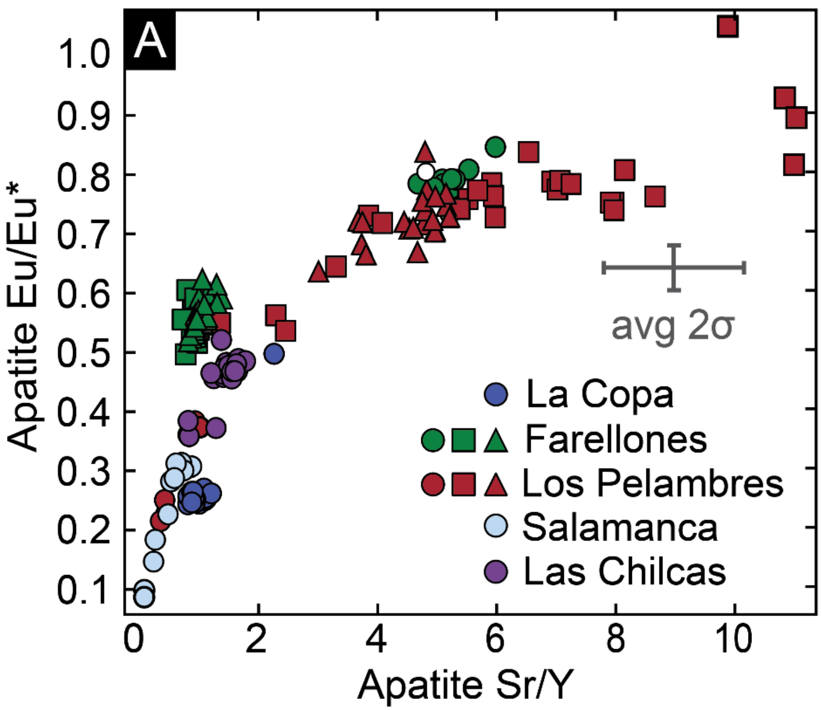


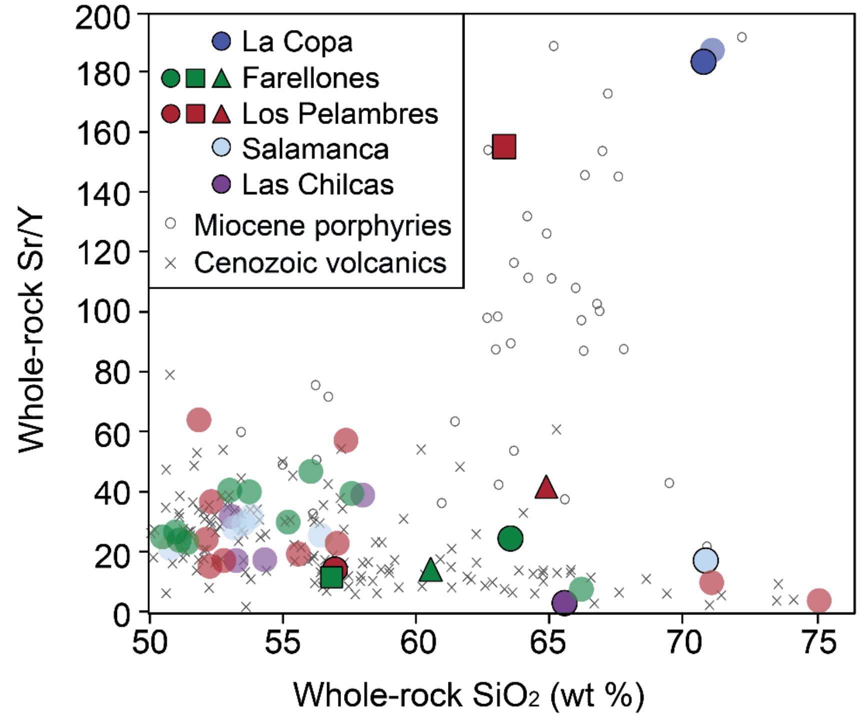

**Apatite Sr and Y are broadly inversely correlated**

Could be representative of fractional crystallization of phases that exhibit compatibility for Sr (plagioclase) and Y (amphibole)?

These concentrations in apatite could also be related to thermochemical influences on apatite-melt partitioning. In order to isolate effects of melt composition on apatite chemistry **we ratio concentrations to minimise changes in partition coefficients**

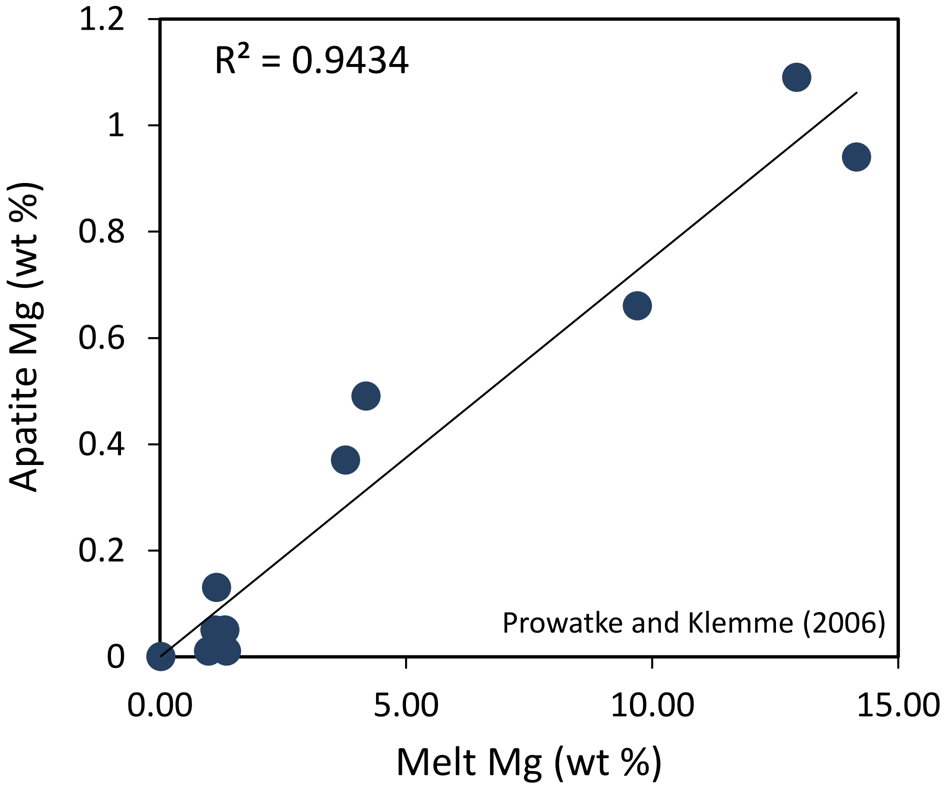
# Apatite Sr/Y and Eu/Eu*



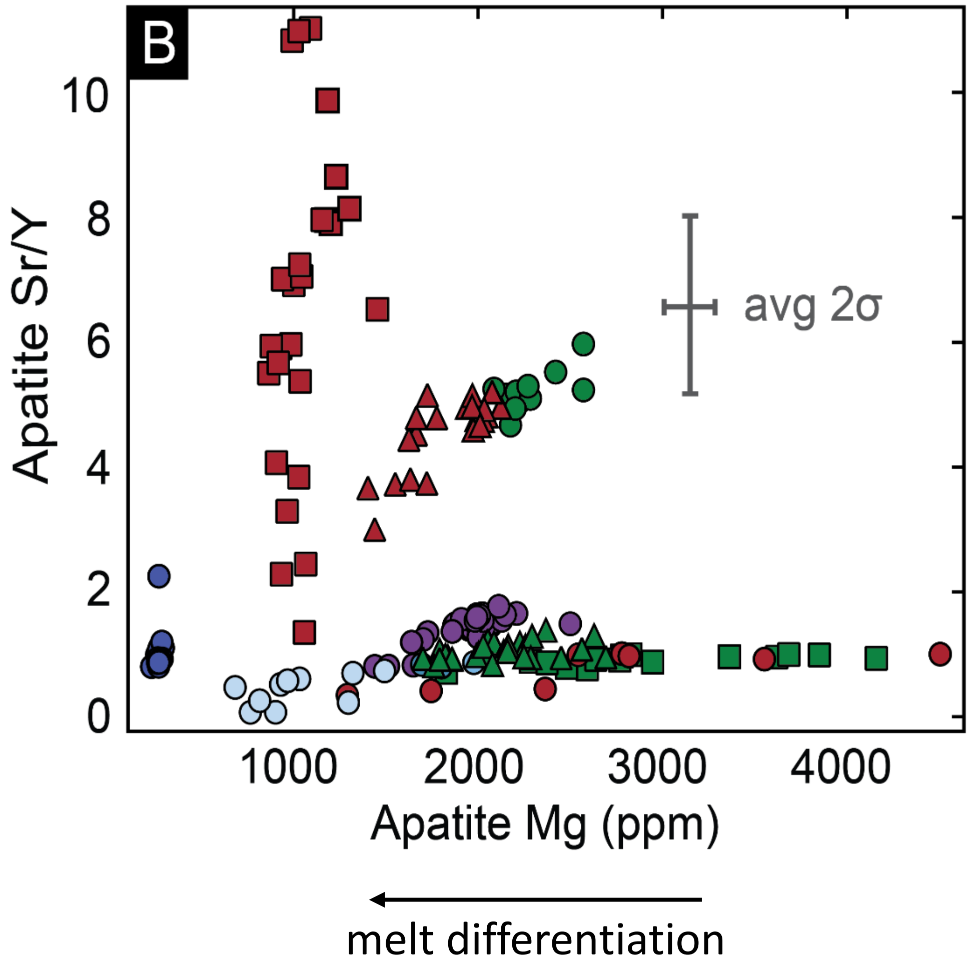

- **Strong covariance between apatite Sr/Y and Eu/Eu***
- Decreasing Sr/Y with decreasing Eu/Eu* could indicate <u>plagioclase crystallisation</u>?
- With the exception of the La Copa sample, high Sr/Y apatites are generally found in the samples with higher whole-rock Sr/Y

# Tracking apatite Sr/Y



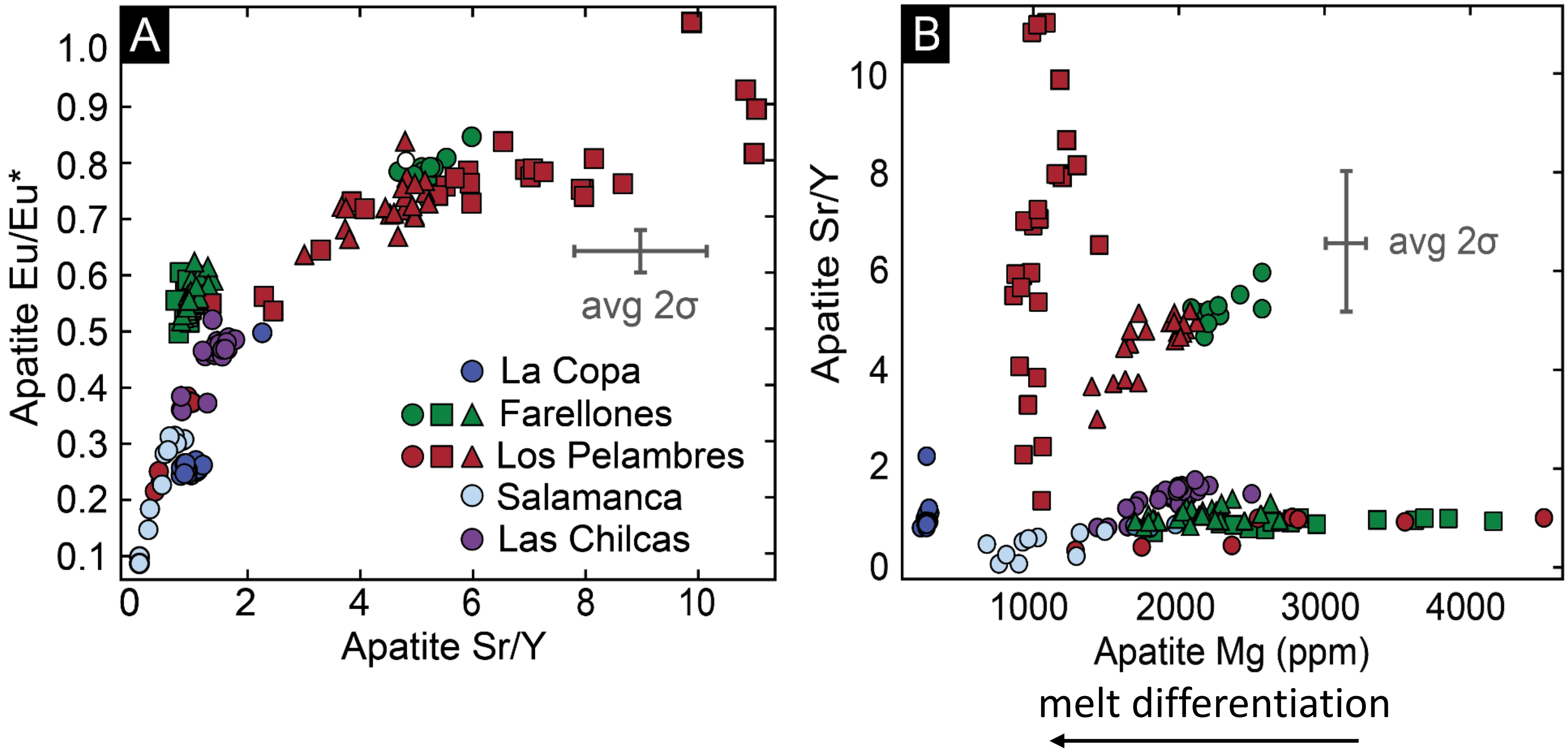

- Experimental petrology has shown that apatite Mg strongly correlates with melt Mg
- Apatite Mg therefore used as a proxy for melt differentiation

# Tracking apatite Sr/Y



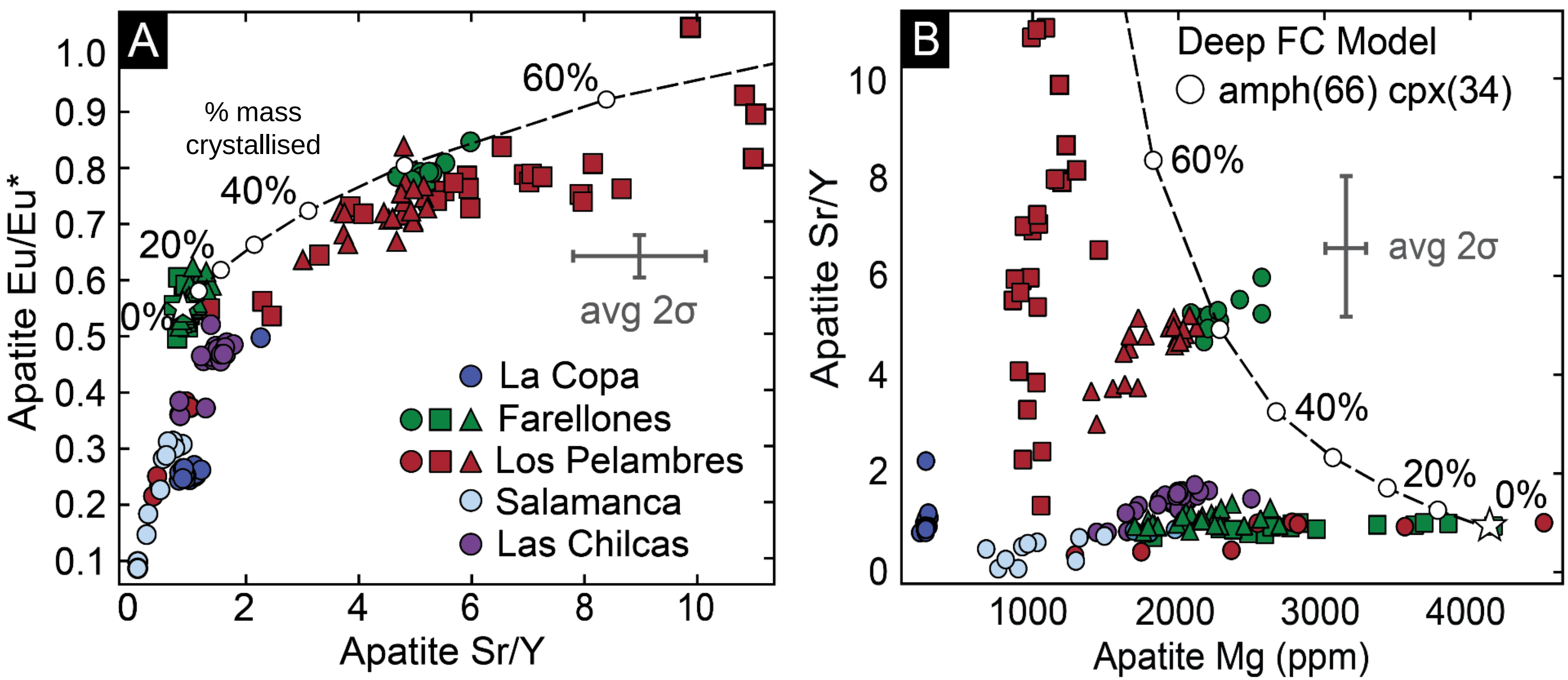

- Apatite Sr/Y vs apatite Mg reveals three separate trends: one where Sr/Y remains low with differentiation (Mg), one where Sr/Y decreases with differentiation, and one where it rapidly decreases within a narrow range of Mg
- No trend of increasing Sr/Y with decreasing Mg observed – **apatite crystallises after the high Sr/Y is generated**

# Deep vs shallow evolution



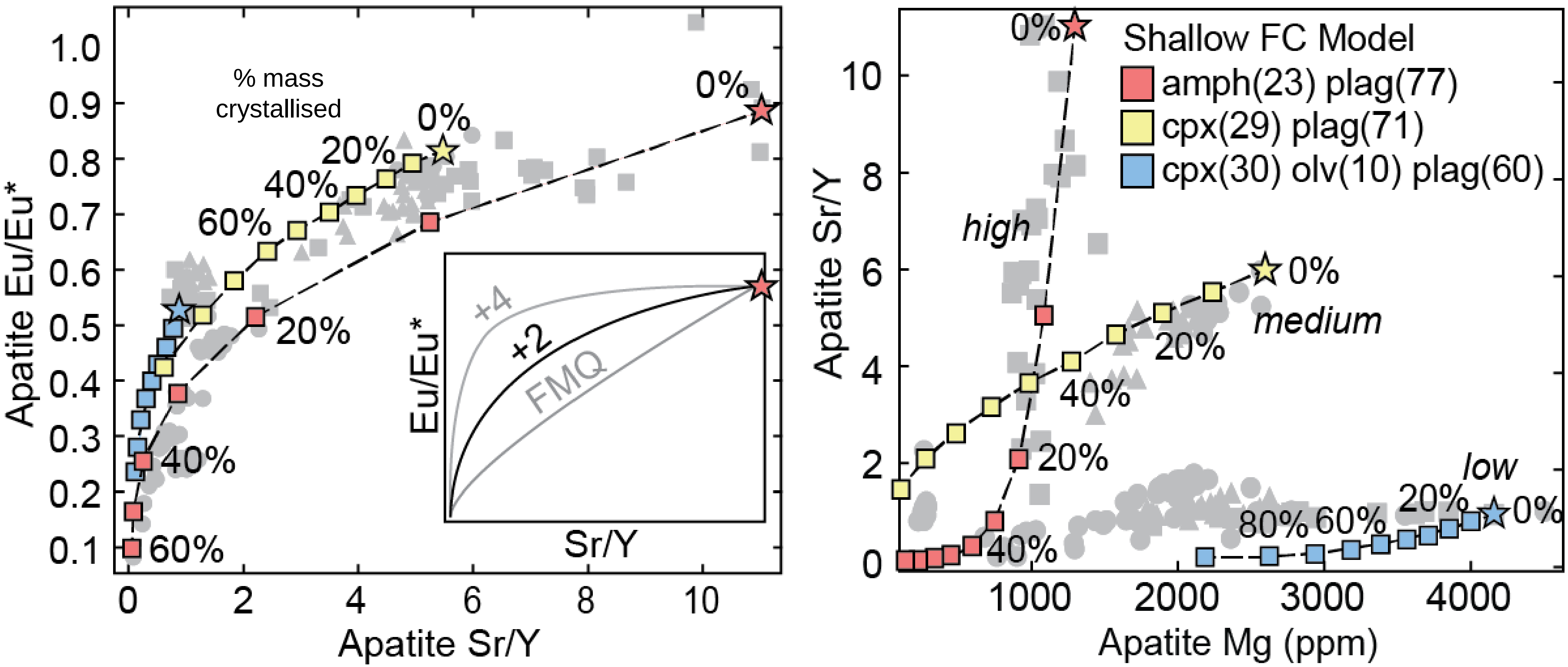

- **We propose that apatite records both deep and shallow crustal melt evolution**
- We use a fractional crystallisation model to demonstrate this – we calculate theoretical apatite compositions under different degrees and styles of fractional crystallisation

# Deep crustal magma evolution



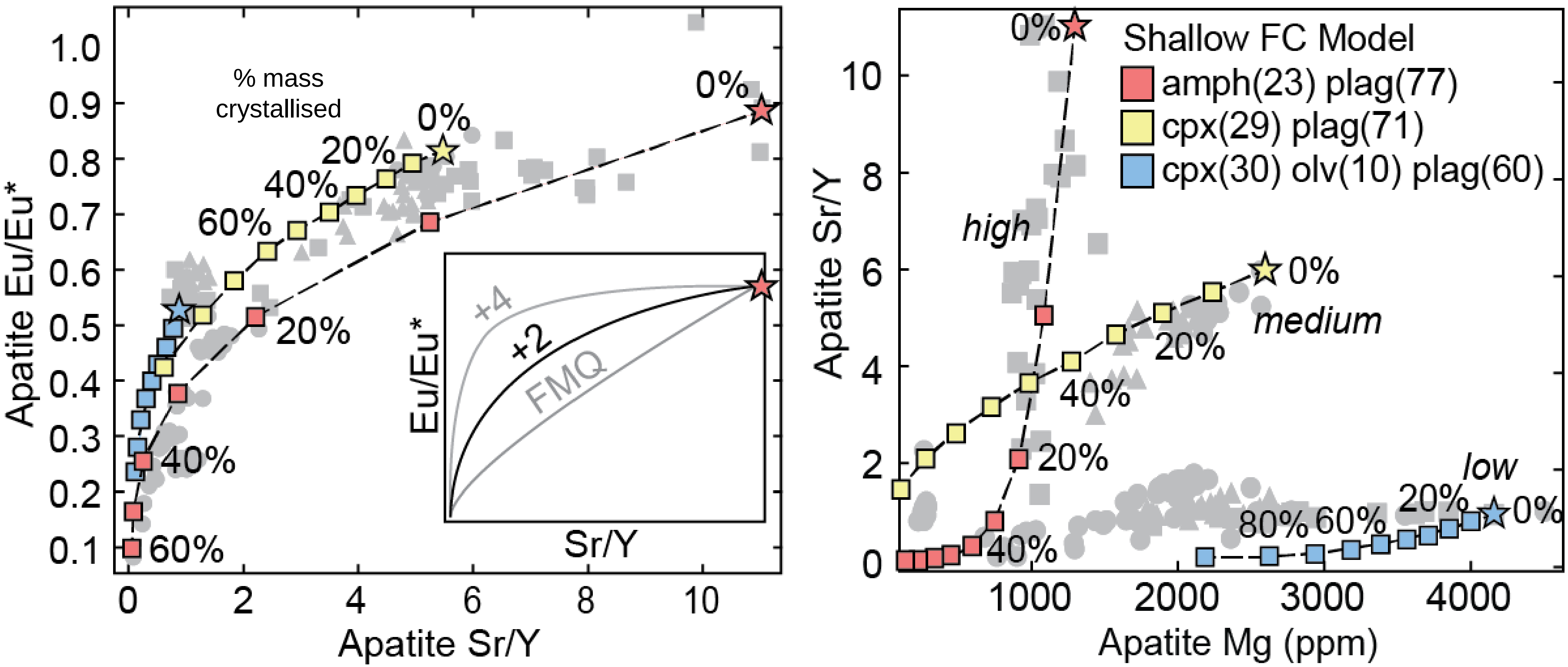

- Fractionation of an amphibole dominated (high water, high P) assemblage typical of the lower crust in thick, metallogenically fertile arcs, produces high Sr/Y, high Eu/Eu* theoretical apatites
- Therefore deep crustal magma evolution prior to apatite crystallisation can produce a high Sr/Y, high Eu/Eu*melt that can inherit this when it crystallises later in the shallow crust

# Shallow crustal magma evolution



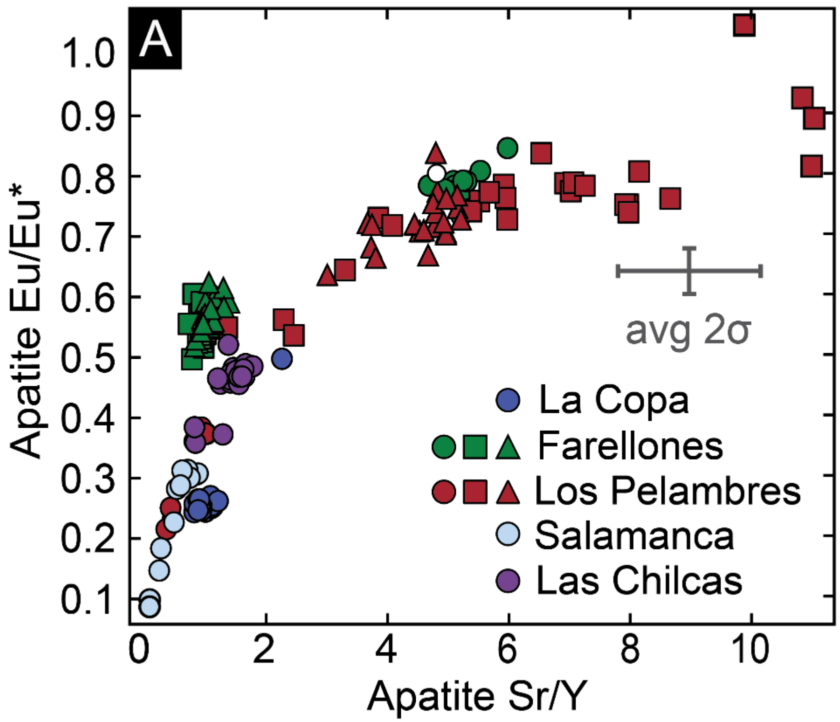

- We took the "starting points" along the three different trends in Sr/Y vs Mg space and crystallised the phenocryst assemblages observed in these rocks
- This represents shallow crustal magma evolution after apatite begins to crystallise; *in situ* crystallisation dominated by plagioclase causes competition for trace elements in the melt
- This causes apatite compositions to decouple from bulk magma/whole-rock chemistry

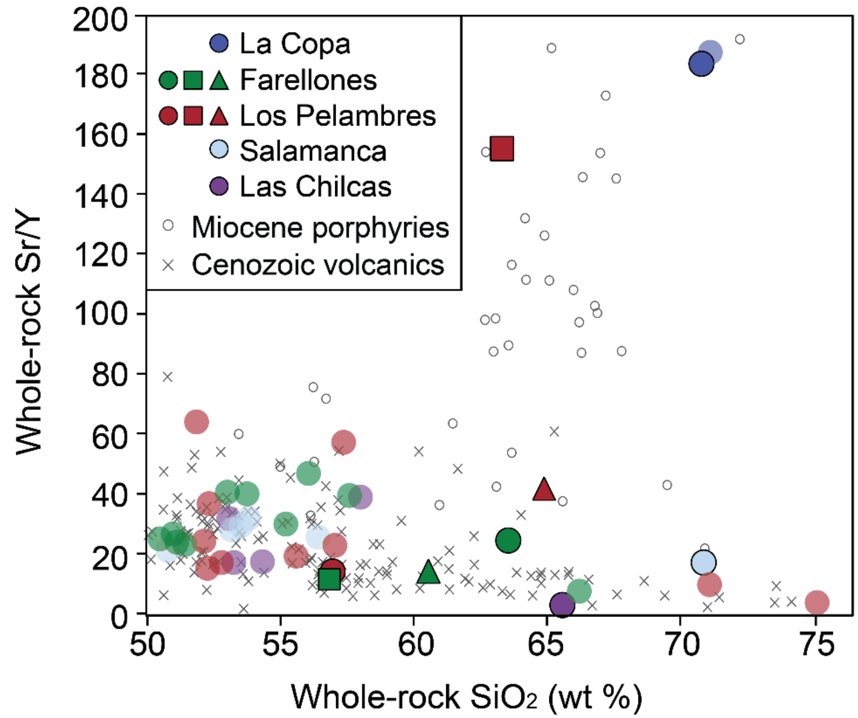
# Shallow crustal magma evolution




- Our model is redox sensitive and the modelled covariance of apatite Eu/Eu* and apatite Sr/Y is sensitive to *f*$O_2$
- We found that the curve of apatite Eu/Eu* and Sr/Y is best reproduced at FMQ+2(±1) – i.e. typical for an arc magma

# Apatite records multi-stage arc evolution



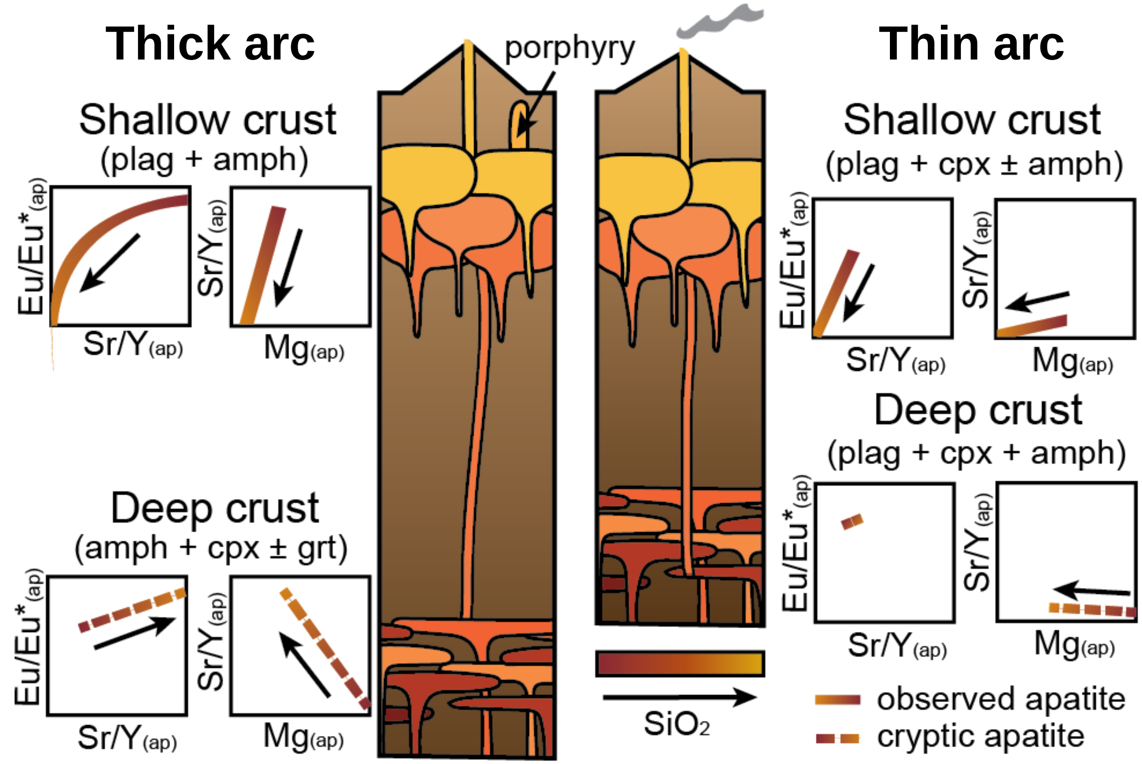




- This model explains the relationship between apatite and whole-rock chemistry
- Generally, apatite inherits the bulk/whole-rock signature that is pre-determined by lower crustal magma evolution when it crystallises in the shallow crust
- However, late, plagioclase-dominated crystallisation in the shallow crust can obscure this signal, e.g. in La Copa (CA30; rhyolitic and most evolved sample) plagioclase crystallisation prior to apatite has eliminated high Sr/Y in apatite but is still preserved in the whole-rock

# Summary and implications

Implications:

1. Apatite is an excellent recorder of arc magma evolution
2. Decoupling of apatite from bulk rock chemistry signature adds complexity to reconstructing host rock chemistry in provenance studies
3. Apatite's ability to fingerprint hydrous deep arc magma evolution can assist fingerprinting fertile magmas that may form porphyry ore deposits




**Apatite can record deep crustal magma evolution but this is overprinted and obscured by later shallow crustal magma evolution**